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Comparative Study of the Influence of Antireflective Coatings and Transparent Oxides on a CdS/CdTe Solar Cell

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Abstract In this paper, we have studied the transparent oxide antireflective effects coatings on solar cell transmission at the n-CdS/p-CdTe heterojunction. We start from the results obtained on the determination of the optical constants by the dielectric function model which takes into account the contribution of the intermediate states. Thus, the transmission is studied to function to epitaxial layers thicknesses of cadmium sulphide CdS and transparent oxide ITO. Our results are compared with those of others authors for different calculation models. Thus, the study is extended to other transparent oxides such as Nb_2O_5 and Ta_2O_5 and to observe the effective influence on the quantum yield of the CdS/CdTe photocell. A table linking the transmission and the reflectivity of its various oxides as function to the thickness could thus be established.

Keywords: *transmission, reflection, quantum efficient, solar cells, heterojunction, cadmium telluride, cadmium sulfide*

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1. Introduction

The current research directions and developments in the field of solar photovoltaic energy are based on the one hand, on the development of new processes for growth of multi-crystalline silicon, reduction of thicknesses and improvement of devices and other semiconductor compounds. Among these, heterojunctions based on cadmium sulphide (CdS) and cadmium telluride (CdTe) still attract the attention of researchers [1,2,3,4]. These heterojunctions among others, less expensive, have advantages both in the realization of the various components that the diversity of possible methods of preparation. The n-CdS/p-CdTe cell is a heterojunction between two binary cadmium compounds: sulfide and tellurium. The junction between these two materials CdS and CdTe presents good prospects for the improvement of solar cell yields. In this paper, we will highlight the importance of CdS/CdTe thin film solar cells made on glass substrates. These are promising for the conversion of photovoltaic energy for large-scale applications. During this part we will theoretically establish the optical constants (absorption coefficient, reflection coefficient and transmission coefficient). Secondly, we will make simulations to obtain theoretical results (reflection curves and transmissions of CdS/CdTe cells) that we will analyze and make a comparative study between the theoretical and experimental results.

2. The Solar Cell Heterojunction Model

The CdS/CdTe structure cell in Figure 1 is shown schematically below with its different components.

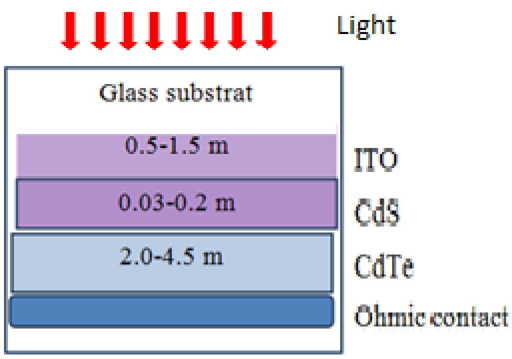

Figure 1. Classic CdTe cell prototype [5]

The typical structure of our CdS/CdTe solar cell is composed of 4 layers and it describes as follows:

The layer of transparent conductive oxides (ITO), which is called frontal contact and has certain required properties such as: high transparency (more than 85% in the visible range), good conductor at room temperature, and good adhesion to the glass substrat.

The CdS layer is also called the window layer. This layer is used as n-type semiconductor. The CdS has some required properties such as: a relatively high transparency, not too thick to promote absorption in the absorber layer of CdTe, not too thin to avoid short circuit, relatively high conductivity to reduce electrical losses, and higher photoconductivity so as not to alter the spectral response of solar cells.

The CdTe layer is also called the absorber. It is placed above the CdS layer and is used as a p-type semiconductor. Since CdTe has an ideal forbidden band energy of~1.5 eV and a high absorption coefficient (10-4 cm^{-1}), a thin CdTe layer is sufficient to absorb most of the incoming sunlight. Metal contact layer which is called the back contact and is deposited on top of the CdTe layer. This layer must have a high working function (>4.5 eV) to form an Ohmic contact with the CdTe and Au layer used in most cases. In addition, Ni-based contacts have also shown promising results. The optical constants of the CdS: Optical constants such as the complex refractive index n*(E), the normal incidence reflection coefficient R(E), the absorption coefficient α(E) and the transmission coefficient T(E) are calculated from the dielectric function ε(E) [6,7,8].

3. Optical Parameters

The refractive index n*(E) = n (E) + ik (E) is a complex function of the refractive index n (E) and the extinction coefficient k(E). These constants are up and can be determined from optical measurements through the real and imaginary parts ε_1(E) and ε_2(E) of the dielectric function [9].

$$\varepsilon_1 = n^2(E) - k^2(E), \tag{1}$$

$$\varepsilon_2 = 2n(E)k(E). \tag{2}$$

From these two equations, the refractive index and the extinction coefficient are obtained by well-known conventional combinations [10].

$$n(E) = \left(\frac{\left[\varepsilon_1(E)^2 + \varepsilon_2(E)^2 \right]^{1/2} + \varepsilon_1(E)}{2} \right)^{1/2}, \tag{3}$$

$$k(E) = \left(\frac{\left[\varepsilon_1(E)^2 + \varepsilon_2(E)^2 \right]^{\frac{1}{2}} - \varepsilon_1(E)}{2} \right)^{\frac{1}{2}}. \tag{4}$$

The reflection coefficient or normal reflectance is easily deduced from the refractive index n (E) of the extinction coefficient k (E) from the following relation [11]:

$$R(E) = \frac{\left[n(E) - 1 \right]^2 + k(E)^2}{\left[n(E) + 1 \right]^2 + k(E)^2}. \tag{5}$$

However, the previously established expression of k (E) and n (E) allows us to obtain the reflection coefficient as a function of the real and imaginary parts of the dielectric function ε (E).

The absorption coefficient of cadmium sulphide is the essential parameter in this study and its expression is obtained by the relation [12].

$$\alpha(E) = \frac{4\pi}{\lambda} k(E). \tag{6}$$

By neglecting the absorption phenomena, the transmission of the normal incidence light in each layer is given:

$$T = 1 - R. \tag{7}$$

According to the absorption losses in the ITO and CdS layers as well as the reflection losses of different interfaces, the previous equation can be written in the following formula can be used to measure theoretically the effect of reflectivity from the back contact on the internal quantum efficiency [13].

$$T(\lambda) = \left[1 - R(ITO) \right] \left(e^{\left(-\alpha_{ITO} \times e_{ITO} \right)} \right), \tag{8}$$

$$T(\lambda) = \left[1 - R(CdS) \right] \left(e^{\left(-\alpha_{CdS} \times e_{CdS} \right)} \right). \tag{9}$$

With R (CdS) and R (ITO) are respectively the reflections of the CdS and ITO layers. d_{CdS} and d_{ITO} are the respective thicknesses of the CdS and ITO layers [14].

4. Results and Discussions

In this part, we will make a comparative study between our theoretically results and those obtained by H.A. Mohamed. The material deposited as anti-reflective layer is ITO. This study focuses on the thickness effect of on ITO and CdS layers. Thus, Figure 2 represents the variation of the glass/ITO/CdS transmission as a function of the wavelength with the CdS thickness set at 100 nm and that of the ITO varies. But also we fixed the thickness of the CdS layer (d_{CdS} = 100 nm), if we varied the thickness of the ITO layer from 100 to 300 nm, we noted that for short wavelengths, we have an increasing transmission. Then in the wavelength range 550 nm to 850 nm, the transmission increases slowly before decreasing. At wavelength 550 nm-850 nm, a transmission of about 0.83 is observed for $d_{(ITO)}$ =100 nm and d_{CdS}=100 nm. With increasing the thickness of ITO, further decrease in the transmission can be observed. Where at d_{ITO}=300 nm, the average value of the transmission is 0.80 in the wavelength range of 550 nm-850 nm. Much more decreasing in the transmission is seen in the wavelength 500 nm due to the absorption of significant part of the incident light in both ITO and CdS layers.

The effect of the thickness of CdS on the transmission spectra is shown in Figure 3. We studied the transmission of the glass/ITO /CdS solar cell as function of the wavelength while fixing the ITO thickness (d =100 nm) and to vary CdS thickness to 100 at 300 nm. By analyzing this Table 1, we noted a fast increase in the transmission variation for high wavelengths, that is to say 700 nm to 850 nm. The variation of the transmission becomes almost constant for wavelengths greater than 800 nm. In addition, we have noted that the variation of the transmission with the minimum thickness is greater than the others over the entire wavelength range. We can interpret these phenomena by the fact that the ITO material used as antireflection layer is transparent resulting in a massive penetration of the flux of photons incident on the latter. This causes a high absorption by the CdS layer that is to say a large transmission. The results summarized in Table 1 is in perfect adequacy with the results obtained experimentally [14,15].

These curves show that the thickness of the layers is an important factor when obtaining a good performance of the solar cell. But they also tell us about the existence of the dual property of the ITO that is to say a significant electrical conductivity and transparency to incident light.

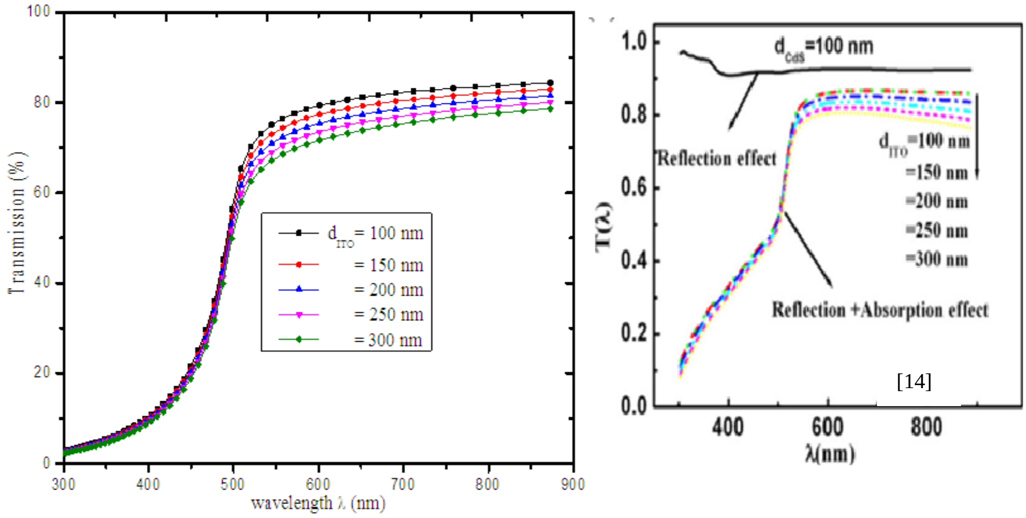

Figure 2. Variation of the glass/ITO/CdS solar cell transmission as a function of the wavelength (fixed CdS thickness)

Table 1. Transmission versus wavelength at different thickness of CdS and ITO fixed at 100 nm and CdS vary

Result of H. A. Mohamed				Our results			
λ(nm) / d(nm)	500	700	850	500	700	850	
100	65.6	82	84	49	84	84	Transmission %
150	57.2	81	83	49	82	82	
200	55.5	79	81	49	81	80	
250	53.2	77	80	48	80	79	
300	51.4	75	78	47	79	77	

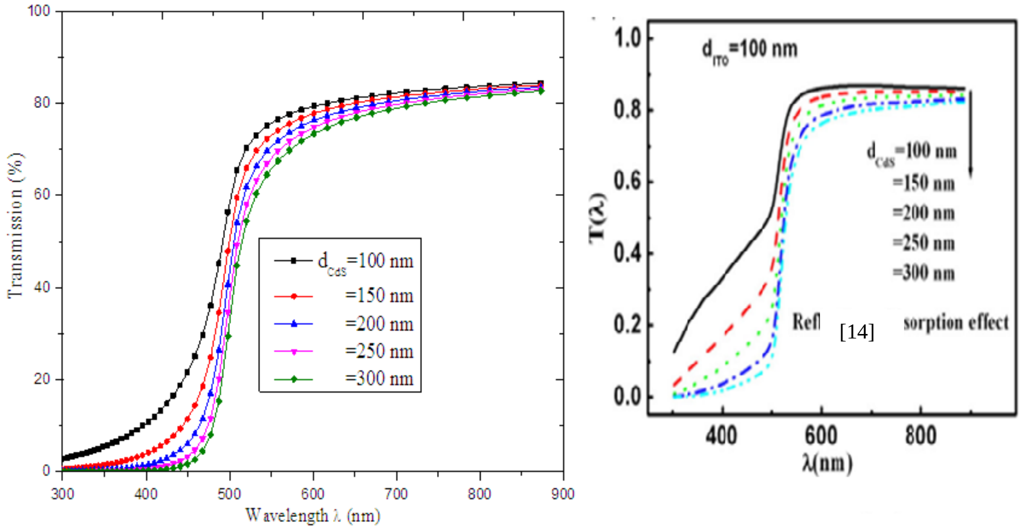

Figure 3. Variation Transmission photo cell glass/ITO/CdS versus the wavelength fixed ITO

Table 2. Transmission versus wavelength at different thickness of ITO and CdS fixed at 100 nm

Result of H. A. Mohamed				Our results			
λ(nm) / d(nm)	500	700	850	500	700	850	
100	65.6	82	84	49	84	84	Transmission %
150	57.2	81	83	49	82	82	
200	55.5	79	81	49	81	80	
250	53.2	77	80	48	80	79	
300	51.4	75	78	47	79	77	

By pushing our studies on CdS/CdTe thin-film solar cells, we will study other TCO materials (Nb_2O_5 and Ta_2O_5) and discuss their yields with respect to ITO. Thus, Figure 4 and Figure 5 respectively represent the variation of the transmission of the solar cells Nb_2O_5/CdS and Ta_2O_5/CdS as a function of the wavelength.

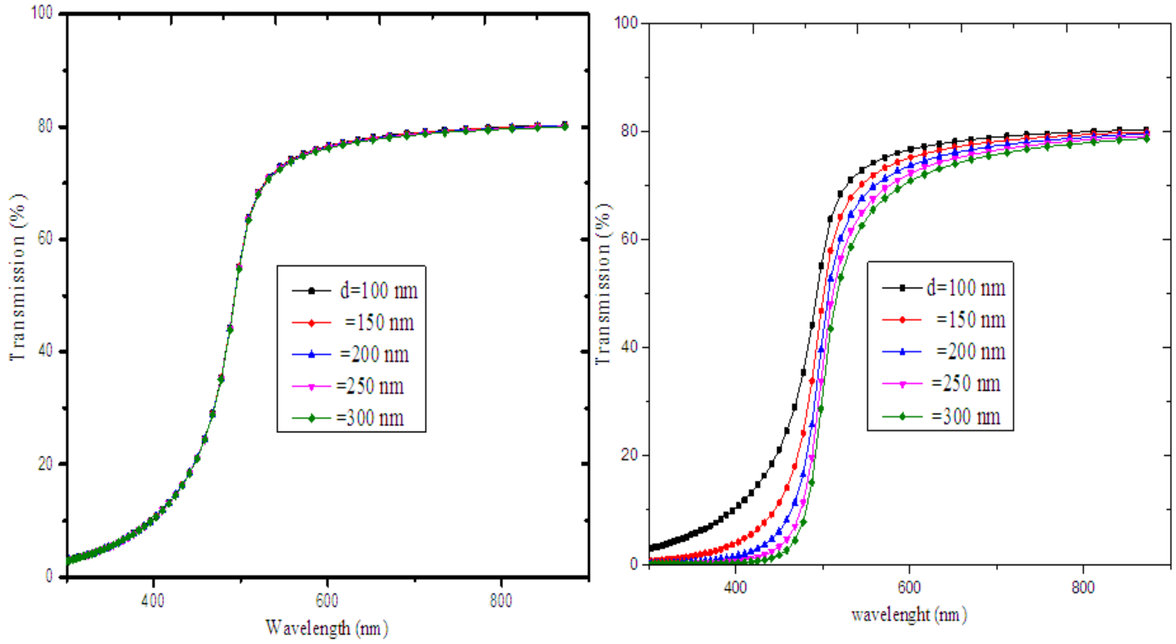

Figure 4. Variation of the transmission of the Nb_2O_5/CdS solar cell as a function of the wavelength

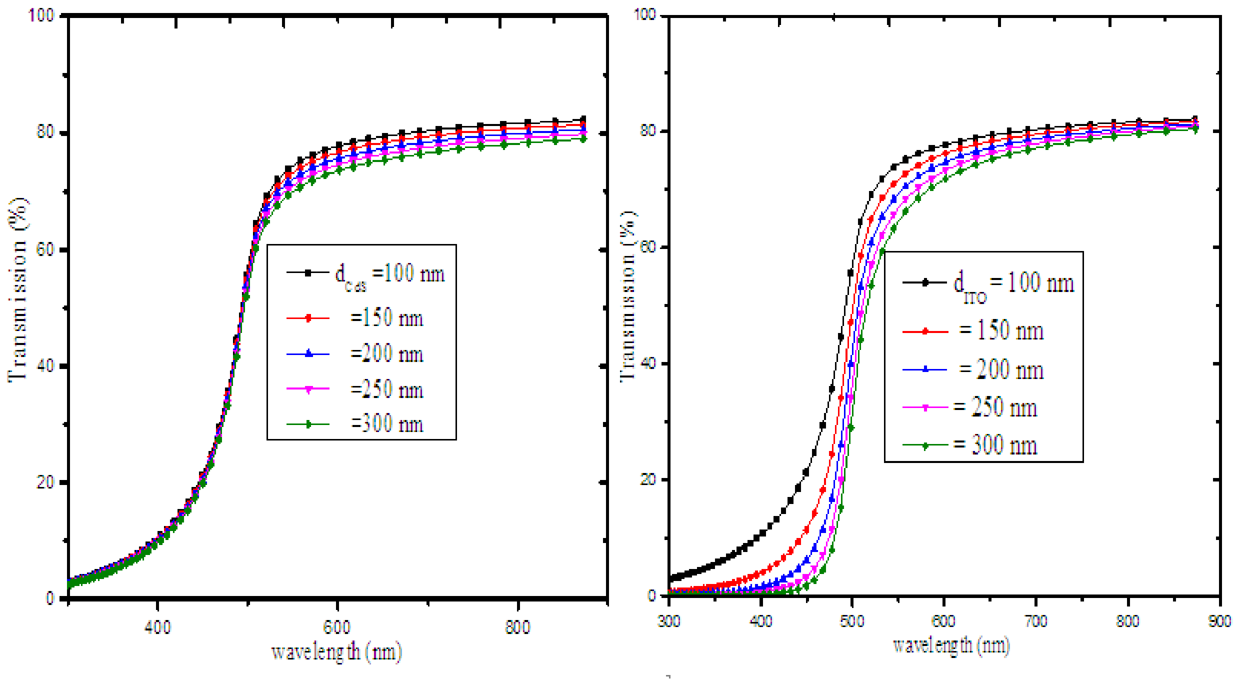

Figure 5. Variation of the transmission of the Ta_2O_5/CdS solar cell

In these two curves of the Figure 4 and Figure 5, we have highlighted the study of the solar cells Nb_2O_5/CdS/CdTe and Ta_2O_5/CdS/CdTe transmission. We did the same procedure as the ITO which is on the one hand fixing the thickness of these two materials to 100 nm and varies the thickness of the CdS and on the other hand to fix the thickness of CdS at 100 nm while varying the thickness of these materials. With respect to these figures, we notice that the evolution of the transmission profile of the Nb_2O /CdS/CdTe solar cell is the same over the entire wavelength range when the CdS has been fixed. But also for Ta_2O_5 this evolution are the same from 300 to 500 nm and for wavelengths greater than 500 nm we notice a slight advance of the one with the smallest thickness. However, for both figures and the thickness of the CdS varies, we noted that the variation of the transmission whose thickness is small significant compared to others over the entire wavelength range. All these phenomena can be linked to the fact that Nb_2O_5 and Ta_2O_5 are like ITO. These are transparent conductive oxides (TCO) and they have about the same physical properties as the latter that is to say a good conductivity and good transparency in the visible range. But also, we noted losses by absorption when the thickness of these materials increases. This causes a smaller variation in transmission. These losses can be attributed by the short-circuit current density.

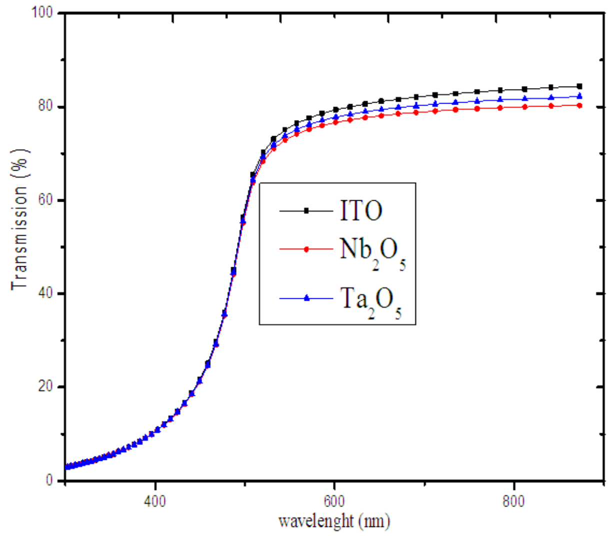

Figure 6. Variation of TCO/CdS solar cell transmission as a function of wavelength

In this Figure 6, we noticed that the evolution of the variation of the transmission through these materials is the same for a range of wavelength between 300 to 500 nm in the visible. For wavelengths greater than 500 nm, we noted a slight increase in the transmission of ITO compared to Nb_2O_5 and Ta_2O_2. The cause of these phenomena can be linked to the fact that for long wavelengths in the visible range, the optical losses, especially by absorption, are greater on these two materials than on the ITO. That is, the absorption losses on the ITO/CdS interface are minimal resulting in an increase in the short-circuit current density on the CdS. This implies that the recombination losses are small.

Reflection of the thin-film solar cell CdS/CdTe

In this part, we will study the reflection of the CdS/CdTe thin-film solar cell while fixing the TCO thickness at 30 nm then 100 nm and the CdS is maintained at 100 nm. Figure 7 shows the variation of the reflection of the CdS/CdTe solar cell as a function of the wavelength.

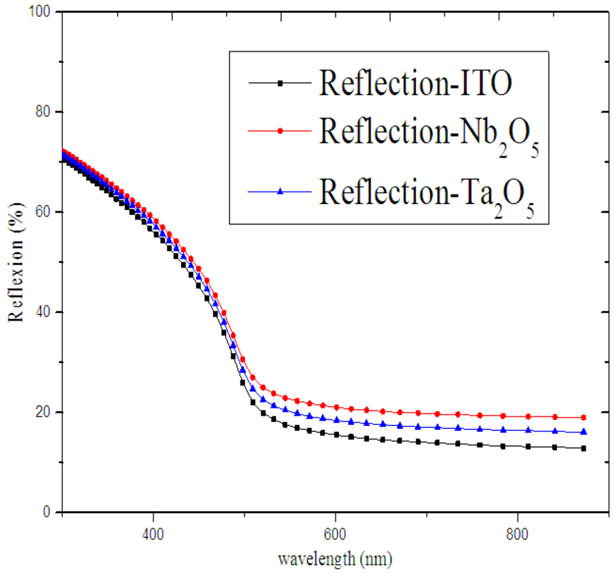

Figure 7a. Variation of the reflection of the CdS/CdTe thin film solar cell at 30 nm as a function of the wavelength

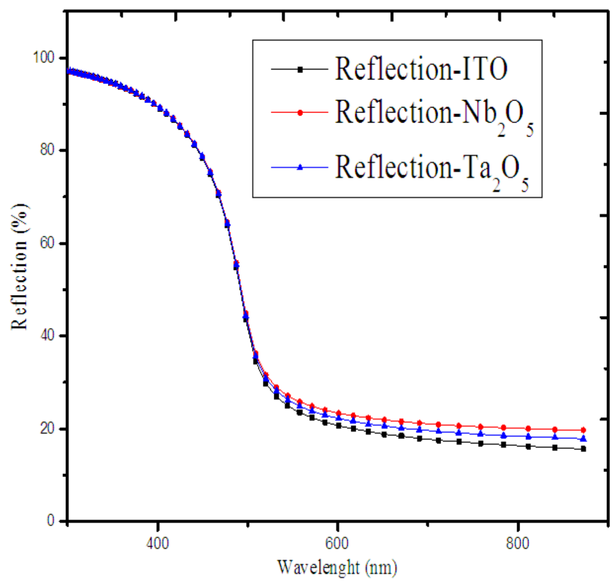

Figure 7b. Variation of the reflection of the CdS/CdTe thin film solar cell at 100 nm as a function of the wavelength

Compared with these figure 7a and figure 7b, we noted a rapid decrease of the variation of the reflection of the TCO for different thickness (300 to 500 nm). But also, we noted that the evolution these three TCO profile is the same over this range of wavelengths. For wavelengths greater than 500 nm, we noted that the variation of the reflection is constant with a slight advance of the ITO curve compared to the others. Moreover, we noticed that the variation of the TCO reflection whose thickness are set at 30 nm is greater than those fixed at 100 nm. The overall interpretation that can be drawn from these analyzes is that more the thickness of the TCO layer is large more than we observe optical losses (by reflection or absorption). These losses influence the performance of the CdS/CdTe thin-film solar cell.

5. Conclusion

In this article, we made a comparative study between this theoretical results and H. A. Mohamed experimental results. This study allowed us to see the thickness effect of the ITO and the CdS window layer on the performance of the CdS/CdTe thin-film solar cell. Thus, the absorption in the ITO and CdS layers reduces the transmission of incident photons, as well as the increase in thicknesses. In addition, by pushing our research on CdS/CdTe thin-film solar cells, we studied other TCO materials (Nb_2O_5 and Ta_2O_5) and discussed their performance with respect to ITO. From there, we concluded that the ITO is more profitable for the thin-film solar cell because having a transmission more important compared to others.

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